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ABSTRACT

Reported is an examination of the use and effects of chlorides as de-icing products for removal of snow and ice from roads immediately following storms. Increasing evidence of detrimental side effects led to a closer look and more careful evaluation of the overall significance of the so-called "bare pavement maintenance." The side effects include deterioration of concrete highway structures, corrosion of automobile and shoe leather, chloride contamination of ground and surface water supplies, damage to roadside vegetation, and toxicity to fish and wildlife of excessive chloride. The chemistry involved is discussed as well as the application problems. Alternative programs are suggested. A bibliography is presented in the report as are selected data tables indicating Tons of Salt Used per Mile for Winter of 1969-1970 for Eastern Massachusetts, Effective Mixture Ratios of Sodium Chloride and Calcium Chloride, Established Sodium and Chloride Limits for Water Supplies, and Snow and Ice Control Costs. (EB)

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DE-ICING SALTS AND THE ENVIRONMENT

prepared by:

THE HABITAT SCHOOL OF ENVIRONMENT

for

MASSACHUSETTS AND NATIONAL AUDUBON SOCIETIES

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I. STATEMENT OF THE PROBLEM

Since 1947, the use of de-icing salts, sodium chloride and calcium chloride in the United States has increased approximately 1800% from less than one half million tons in 1947 to just over 9 million tons in 1970 (27). Bubeck et al., in an analysis of the chloride contamination of Irondequoit Bay, N.Y., cites the nearly exponential growth of salt use with a doubling period of approximately five years (20). Increasingly the trend has been away from using a mixture of sand and salt which emphasized sand toward a total salting policy. Based on the trend of the last five years, the projected chloride usage in this country in 1974-1975 will total over 15 million tons. In Canada just over one and three quarter million tons of chlorides were used in 1969-1970. If the growth trend of the past five years continues, the projected total for 1974-1975 is about two and one quarter million tons (62).

This increasing use of chlorides is due primarily to the increase in popularity of a "bare pavement maintenance" policy which entails removing all snow and ice from roads as soon as possible following a storm (64), i.e., an attempt at simulating June road conditions in January. Salts do melt snow and ice quickly and efficiently, thereby supposedly ensuring public safety and convenience. There is, however, increasing evidence of detrimental side effects which necessitates a closer look and more careful evaluation of the overall significance of a bare pavement policy. These side effects include deterioration of concrete highway structures, corrosion of automobiles and shoe leather, chloride contamination of ground and surface water supplies, damage to roadside vegetation, and toxicity to fish and wildlife of excessive chloride. Also, the relative safety of salted vs. unsalted roads is still undetermined, although the assumed connection between safety and salting has been the basis for the massive increase in salt use to date.

Many states are becoming concerned about these side effects, but Massachusetts appears to be the most active in actually confronting the problem. The towns of Burlington and Concord have gone so far as to ban salt completely because of their concern for water contamination and vegetation damage, while other towns such as Arlington, Lexington, Lincoln, Marshfield, Natick, Newton, Wenham, Weston and Winchester are considering total or partial bans on chloride use.

In a society as highly committed as ours is to the automobile for private transportation, the question of snow and ice control methods is one of great concern. The growing dispute over the advantages as well as the negative aspects of salt use for snow removal necessitates an in-depth, objective look at both sides of the problem. Much of the information presently available to decision-makers and the public has been disseminated by the Salt Institute (formerly the Salt Producers

Association), a public relations organization promoting the sale of de-icing salts. More objective information is generally less available, although the Environmental Protection Agency (EPA) has recently published a major review of the existing literature, Environmental Impact of Highway De-icing (27), which considers questions of environmental stress from salting, but does not treat either safety or economics within its scope. Further research on many salt-related issues is a crucial need.

II. THE CHEMISTRY AND APPLICATION OF DE-ICING SALTS

Chemistry

The two salts most commonly used to melt ice and snow are sodium chloride and calcium chloride. Most of the sodium chloride that is used in the country for de-icing purposes is mined from underground domestic deposits (54) and is sold for about $10 to $15 dollars a ton delivered (27).

chloride

As a de-icing agent, sodium acts by dissolving in water and lowering the freezing point of the resulting solution below that of pure water. As the salt goes into solution, a brine forms which spreads out in all directions, melting more snow and ice and breaking the bond between the ice and pavement. In practice, sodium chloride seems to work most effectively in the temperature range of 32° to 0°F. (54)

Much less calcium chloride is used for de-icing than sodium chloride. Most of the calcium chloride which is used for these purposes is a by-product of various manufacturing processes and is sold for about $40 to $47 a ton delivered (27).

As a de-icing agent, calcium chloride works the same way sodium chloride does - only more so - for on a molecule for molecule basis, it is a slightly better de-icing agent. This, plus the fact that calcium chloride liberates heat upon going into solution, (unlike sodium chloride), makes it important when temperatures fall below the range in which sodium chloride is most effective (27, 54).

Calcium chloride, unlike sodium chloride, absorbs moisture from the air (i.e., it is deliquescent) and for this reason it is used in some areas to dampen the dust along roadways during the summer. Unfortunately, the affinity which calcium chloride shows for atmospheric moisture also results in severe "caking" problems in storage.

Often a mixture of calcium chloride and sodium chloride is used in de-icing work. A mixture of the two has the properties of both (21). The amount of each chemical used generally depends on the temperature - as the temperature falls, more and more calcium chloride is added to the sodium chloride (Table 2).

Special substances are often added to de-icing salts to reduce caking and corrosion (27, 61, 65). These substances are generally added in only small amounts, but they contribute to the overall chemical attributes of "salt." This is especially important to keep in mind when assessing environmental damage that is reputedly due to "salt."

Storage and Application

Salt is typically stored in large piles in designated storage areas of some permanence. An unprotected salt pile can have a profound impact on the local environment since every rainfall will produce a highly concentrated brine runoff from the pile. This can result in the quick contamination of local water supplies. Fortunately, this kind of salt pollution can be alleviated by simply putting the salt pile on an impervious base (with a lip) and covering the top. There are many versatile, inexpensive designs for storage structures employing these basic ideas (27).

Salt is spread continually during a storm and it is not unusual for a given stretch of road to receive three or four applications of salt during a storm. Many towns spread salt before it starts to snow so that the snow melts when it hits the road.

A truck with a salt spreader is used to distribute the salt, and the trucks are provided with regulators to prevent the salt from being scattered beyond the side of the road and also to prevent the salt from piling up when the truck stops.

The Salt Institute recommends applying about one ton of salt per two-lane mile per storm, but, in practice, towns vary greatly in the amounts they choose to use. During the 1969-1970 snow season, for example, 8 towns in eastern Massachusetts, all experiencing the same weather conditions, applied salt in amounts ranging from 8.5 to 55 tons per land mile (73) (see Table 1). This situation is probably typical for other areas of the snow belt.

After Application

After de-icing salts have been applied to the roadway, their side-effects can begin almost immediately, as salts in solution seep into the pavement surface and are splashed to the side of the road. Studies in Iowa, cited by the Environmental Protection Agency (27) give some indication of the various pathways of salt through the environment after they have left the road. About 25 per cent is said to wash away by surface runoff (potentially contaminating streams); approximately 12 per cent leaches through the soil (possibly damaging soil structure and vegetation and contaminating ground water); perhaps 10 per cent is removed through the air; and about 50 per cent is removed by highway traffic, with some portion of this presumably tracked onto parking areas and other roads, some splashed to the side of the road, and some retaining for an undetermined time on the automobile (where corrosion can occur). Eventually all de-icing salts must be removed by drainage to the soil or water. In the following sections, each of the possible side-effects occurring along these various pathways is examined in its turn.

TABLE 1

TONS OF SALT/MILE STREET -- WINTER 1969-1970 FOR E. MASSACHUSETTS*

TOWN	TONS OF SALT PER STREET-MILE
SALT INSTITUTE (RECOMMENDED)	20
LEXINGTON	8.5
BURLINGTON	9.4
STONEHAM	12.7
CAMBRIDGE	21
ARLINGTON	24
MEDFORD	30
NEWTON	32.4
WINCHESTER	55

*21 storms

Source: Untitled Position Paper, Citizens of Winchester, Massachusetts (73)

TABLE 2

EFFECTIVE MIXTURE RATIOS OF SODIUM CHLORIDE AND CALCIUM CHLORIDE

SODIUM CHLORIDE BY WEIGHT	CALCIUM CHLORIDE BY WEIGHT	TEMPERATURE PROTECTION
3	1	Near 30°F
2	1	Near 20°F to 25°F
1	1	With severe icing conditions and low temperature - very effective

Source: Massachusetts Legislative Research Council (54)

III. DAMAGE TO PUBLIC WORKS

Concrete Bridge Decks

A review of the literature indicates that de-icing salts can, under certain conditions, contribute to the deterioration of highway structures, most notably reinforced concrete bridge decks. A direct correlation between damage to bridge decks and the use of de-icing salts has not been found conclusively, according to a 1960 study of bridge damage by the Illinois Division of Highways. In that study, concrete deterioration appeared to be evenly distributed across the state, despite rather widely varying snow conditions and the consequent road salting (54). Nevertheless, extensive research has been conducted by the Highway Research Board, over twenty state highway departments and other agencies (23, 27, 40, 54, 71), on the contribution of de-icing salts to bridge deck deterioration, so that a significant correspondence can be inferred.

Salt-related damage to concrete bridge decks generally occurs as scaling and spalling (see Appendix A). Enough of the mechanisms of these two types of damage is now known so as to make it well within the capability of the construction industry to prevent scaling and to greatly inhibit spalling. In the case of spalling, the service life of a concrete deck is largely dependent on the depth of concrete cover over the reinforcement (40), although, over time, some spalling would appear to be inevitable given continued use of de-icing salts.

Road Surfaces

While bridge decks are surfaced with cement concrete, highway pavements can be surfaced with either cement or bituminous concrete. Instances of scaling or spalling of cement concrete pavement are far less frequent than found in bridge decks, because pavements involve fewer structural problems and are generally subject to less stress. This reduces the occurrences of hairline cracks which are an important contributing factor in salt-related concrete damage.

Bituminous concrete (which substitutes asphalt as the cementing agent) is not considered to be susceptible to salt-related damage (54). Asphalt surfaces are also considered resistant to damage by de-icing salts, and where damage is seen on either bituminous concrete or asphalt pavements, improper construction practice and/or poor drainage can be suspected (54).

Underground Utilities

Several reports have been recorded of corrosion damage to underground power transmission lines (82), transformers, telephone cables and water mains (27, 39) in part due to high chloride concentrations in ground waters near these utilities. There is, however, little data available either to substantiate or to disprove these reports.

IV. AUTOMOBILE CORROSION

The extent to which de-icing salts contribute to the corrosion of metal parts of automobiles is still a matter of debate, but a survey of available data does indicate that the contribution is substantial. Corrosion of steel parts involves the combination of iron with atmospheric oxygen, in the presence of moisture, and these factors can be present with or without the participation of road salt. As the salt industry stresses, salt by itself does not corrode (63). But extensive research does demonstrate that chlorides, whether airborne from the oceans or splashed onto cars from de-icing operations, can and do play an important role in accelerating the corrosion process (3, 27, 34, 54, 63). Recent tests by the American Public Works Association, referred to in the major study of de-icing salts by the Environmental Protection Agency (27), indicate that "up to 50 per cent of vehicle corrosion can be attributed to de-icing salts on streets and highways." Also, a research program conducted by the University of Manitoba reportedly concluded that de-icing chemicals double the corrosion rate over that likely to be experienced in their absence (3).

Estimates of Damage

Attempts to estimate the costs of corrosion damage to vehicles generally refer to damage to the underside, body and trim, and are usually translated into dollar costs to the motorist at the time of trade-in or resale. Estimates vary widely, from $5 per year (salt damage only) (46) to $200 per year (73), with the most authoritative estimate, by the Society of Automotive Engineers, set at "about $100 a year" for rust destruction (27). Also, one cost estimate by the EPA (27) for the corrosion of mufflers and tailpipes (to which salt may be an important contributor) reaches "about $500 million annually" for the nation. While any figures will range widely by region, it is reasonable to conclude that the dollar costs to the motorist each year are substantial.

Another aspect of corrosion damage to automobiles cannot be measured by dollars alone: the potential safety hazard stemming from rusted body frames. A spokesman for the U.S. Department of Transportation, Office of Defects Investigations, reports that the office has received numerous reports from Connecticut, Massachusetts, Michigan, Ohio and other states of corrosion so extensive that it has completely ruptured the frame rails of some 1965 Chevrolet automobiles. According to a spokesman for the State Department of Dealers and Repairs, Department of Motor Vehicles, Connecticut alone has had over 200 automobiles taken off the road for this problem. Causes of this severe corrosion that have been mentioned are lack of owner maintenance, design of the frame and road salt, although any conclusions must await the results of a study being conducted by the University of Connecticut. Nevertheless, existence of this localized problem does suggest the potential hazards of automobile corrosion to public safety.

Mechanism of Corrosion

Corrosion of steel is an electrochemical reaction involving the oxidation of iron in the presence of moisture. Salt acts as an electrolyte in the process by donating highly mobile chloride ions which increase the electrical conduction of the solution. The rate of corrosion will depend on a number of factors including the degree of exposure of the steel to oxygen in the air, the amount of water present, and the amount of salt. When the enamel or lacquer body paint, which normally provides a highly protective bond, becomes chipped, steel becomes exposed to air and the process begins. Once started, the corrosion can spread beneath the remaining print film, lift it and expose the rusted metal. Obviously certain road conditions, such as flying stones and pebbles, moisture-retaining dirt and salt spray, can act together to begin the chipping and corroding sequence. Studies in Iowa, cited by the EPA (27), show that approximately 50 per cent (a very rough figure) of the de-icing salts are removed from the road surface by traffic under normal conditions, although it is uncertain what proportion of this 50 per cent is retained on the car body. Factors such as the design and construction of the automobile, the presence of dirt-catching troughs, crevices or joints, and the propensity of its paint or undercoating to chip, will combine with road conditions to determine the ability of the vehicle to resist attack. In addition, other environmental factors, such as the presence of industrial pollutants in the atmosphere may contribute to the process (3, 27, 34, 54).

Tests conducted by the Ford Motor Company on various types of metals used in automobile parts (11, 54, 75) indicate that of the two chloride salts commonly used for de-icing, calcium chloride causes corrosion which is almost twice as severe as that of sodium chloride. Because calcium chloride not only retains (as does sodium chloride) but attracts moisture, it continues to aid the corrosion process even in relatively dry atmospheric conditions.

Methods of Prevention

Theoretically automobile corrosion can be prevented by removing any one of the three factors necessary for the oxidation reaction to occur (steel, oxygen, moisture), and can be inhibited by removing factors which normally accelerate the process (such as de-icing salts). Until chipped or scratched, the original automobile paints and undercoatings serve to prevent corrosion by separating steel parts from oxygen, moisture and salt. Once these are broken, however, the resultant cracks or crevices can trap dirt and moisture and thus abet corrosion (27, 34, 54). A number of manufacturing innovations by the automobile industry have been cited by the Salt Institute as reasons to conclude that recent models will be less susceptible to corrosion due to better automobile design (63). These

principles adopted in the early 1960's include the elimination of dirt and moisture catching joints and pockets, whole-body dipping and electrostatic painting techniques, drainage parts spotted in key places, galvanized steel and zinc-rich paints, welded joints, splash shields, cadmium plating of critical parts, and spraying car underside and interior with a wax material resistant to corrosion. Evidence of the degree of success of these techniques is not readily available, although a review of the current literature (27) indicates that corrosion is still a significant problem even in later model vehicles.

A number of substances developed as corrosion inhibitors to be added to de-icing salts have been developed, but, as indicated by the EPA study (27), little data is available on past and present use (which is believed to be significant), costs or proven effectiveness. Inhibitors are usually coated on the outside of salt granules and are eventually dissolved with the first quantities of salt and splashed to the side of the road, thus reducing the concentration of inhibitor in the remaining brine (34). The EPA divides inhibitors into three catagories, identified as hexavalent chromium, trivalent chromium and hexametaphosphate. Each of these is suspected of having specific environmental side-effects, representing physiological dangers to either humans, animals or plants, and the EPA stresses that environmentalists should be aware of the potential dangers whenever these substances are used (27). Results of controlled tests of a sodium polyphosphate inhibitor conducted in Toronto showed an estimated 25 per cent reduction in total corrosion (34). Tests conducted on certain inhibitors by the Ontario Department of Highways, as reported by Fromm (34), concluded that, "From an economic point of view, none of the corrosion inhibitors tested produced a worthwhile reduction in the amount of corrosion."

Conclusion

While there exists extensive evidence that de-icing salts have an accelerating effect on the automobile corrosion process, and that the damages accrued are significantly costly to the motorist and possibly dangerous, no data exists showing that corrosion can be successfully prevented by existing techniques relating to either automobile design or chemical additives to de-icing salts, nor does sufficient data exist showing the rate of corrosion decline nationally since the introduction of these techniques.

V. WATER POLLUTION

Introduction

During the past 30 years, increasing use of highway de-icing salts has resulted in increasing contamination of various fresh water resources. Natural sources of chloride, such as rainfall, seawater, surface runoff and natural brines do exist, as do other man-made sources, such as industrial wastes. But the volume and location of the increase in chlorides clearly shows that de-icing salts are an important factor. Research has been done on several kinds of salt pollution, including that in groundwater, wells, lakes, rivers, streams and direct highway runoff. The effect of these increased chloride levels is seen most clearly in groundwater and wells which serve as public water supplies. Groundwater pollution is particularly dangerous, since by the time it reaches a level of public alarm, it is almost impossible to reverse. In surface waters, the dilution factor has so far been large enough to minimize any serious problems. However, chloride concentrations are on the increase in some streams, rivers and lakes, and this trend must not be overlooked.

In this section there are a number of references to chloride and sodium levels which are expressed as either milligrams per liter (mg/l) or its equivalent, parts per million (ppm). In order to put these figures into perspective, established limits are given in Table 3.

TABLE 3

ESTABLISHED SODIUM AND CHLORIDE LIMITS FOR WATER SUPPLIES

CHLORIDE

For potable water, Federal Department of Public Health:
- 250 mg/l - maximum level
- 25 mg/l - recommended level

For Industrial Use*:
- 760 mg/l - food canning and freezing
- 200 mg/l - carbonated beverages, food equipment washing and paper manufacturing
- 175 mg/l - steel manufacturing
- 60-100 mg/l - textiles, brewing
- 20-30 mg/l - dairy processing, photography and sugar production

*Source: EPA (27)

SODIUM

For low salt or salt-free diets:
- 22 mg/l - American Medical Association limit

Highway Runoff

The runoff from streets and highways that have been treated with de-icing salts contains large amounts of sodium chloride and calcium chloride. Several studies conducted in various areas of the United States, e.g., Wisconsin, Syracuse and Chicago, have investigated the amount of salts in highway runoff.

During the year 1956-1957 several sampling stations were established throughout Wisconsin to monitor the runoff from salt-treated highways. Schraufnagel (36) reported that in the Chippewa Falls area, wintertime highway runoff contained up to 10,250 mg/l chlorides. This decrease in chloride concentration was a result of dilution. Street runoff during the summer contained 16 mg/l chlorides and the receiving stream ranged from 0.5 - 2.0 mg/l chlorides. Thus the late summer runoff had smaller amounts of de-icing chemicals than did the winter runoff. This appears to be a fairly typical seasonal pattern.

In Syracuse, New York, Richard Hawkins (27) studied the retention of highway salts in streets including the snow and ice cover, street surface and directly within the street masonry. He observed summer reappearance of salt moving upward through the concrete onto the street surface. The presence of salt was easily confirmed by a "finger tip taste test." Thus, throughout most of the year these salts are continually being released onto street surfaces and into storm sewers.

In another study Sullivan (as cited in 27) monitored the chloride content in runoff from the Kennedy Expressway in downtown Chicago during the winter of 1966-1967. The highway drainage area consisted of 102 acres, half of which was paved. The study calculated that a chloride level of 1,300 mg/l could be expected in the runoff, assuming 1.5 tons of salt are applied per mile of two-lane highway for each inch of snowfall. The salt content of highway drainage was found to depend upon many factors, including temperatures, amounts of precipitation, quantity of salt applied, traffice patterns, and volume and rate of surface flow. Sullivan recognized that wintertime runoff will eventually run into fresh water streams and into lakes or ponds. Two suggestions were offered: (1) in critical areas, "monitoring...should be carried on at various depths to detect significant changes in concentration" and (2) "if a chloride balance is to be maintained in a river to limit chloride to an acceptable level for potable water supplies, the runoff from urban areas must be accounted for and allowances made in the discharge rates from industrial plants at the time of any low winter flows."

Streams

The application of de-icing salts to streets with its resulting runoff has a measurable effect on streams, as is shown by various stream

surveys conducted in Maine, New York and Vermont.

In a study conducted in the Kenduskeag Stream basin in Bangor, Maine, Hutchinson (as cited in 27) sampled a culvert from Interstate 95, two storm drains and a brook, all of which flowed into the stream. Tests of the area upstream and downstream from the points of entry of the drains and brook were also made. The highway culvert showed the highest level of sodium and chloride with mean values of 168 mg/l and 570 mg/l, respectively. The two storm drains contained runoff with average sodium content of 26.8 - 28.8 mg/l and average chlorides of 73.9 - 84.6 mg/l. The upstream waters of Kenduskeag Stream contained sodium and chloride levels of 3.9 mg/l and 6.5 mg/l respectively. Downstream of the storm drains and the brook, the Kenduskeag Stream running through the center of the city showed average sodium and chloride levels of 5.3 and 10.0 mg/l, respectively. Since there was little industrial pollution in the area, Hutchinson concluded that "road salt contamination" was significant in these waters. The data indicated that there is a high concentration of chlorides in the runoff but the dilution factor reduces the concentration.

In Syracuse, New York, Hawkins (cited in 27) studied the Meadow Brook watershed area which includes four square miles of fairly well developed land. He concluded that (1) salt runoff from the watershed is discharge in winter and spring-high concentration periods; (2) salt concentration in the stream is dependent on amounts of snow and salt as well as the temperature; (3) chlorides decrease during spring and summer but are detectable thus confirming the retention of salt in the watershed and (4) a close correlation exists between road salting and stream chlorides.

The Sleepers River Basin in Vermont was another area tested for salt contamination (Kunkle 51). This study showed that the salt concentrations of the streams were lowest in the springtime when the dilution factor was the greatest (due to melting snow) and highest in the summertime when the dilution factor was the least. Individual testings near the highway showed chloride levels as high as 200 mg/l. He estimated that 65 to 100 tons of salt were applied in the watershed area of the highway, and concluded that a large portion of de-icing chemicals appear to find their way from the highway by seeping and flowing into surface streams.

The runoff from highways treated with de-icing salts invariably shows high levels of chlorides during the winter and spring, and decreasing amounts in the summer. Eventually this runoff enters streams and has an appreciable effect in the chloride concentration of their waters. These increased concentrations are still fairly low (relative to natural concentrations) but it is clear that as the use of de-icing salt increases, so too will the salt concentrations of our streams.

Ground water

As a result of highway de-icing with salt, there have been increasing concentrations of sodium chloride in the groundwater and public water supplies derived from groundwater sources. The two main sources of this contamination are (1) runoff from salt stock-piles and (2) highway and road runoff.

Salt Stock-Piles Contributing to Groundwater Contamination

Road salt is stock-piled in large quantities to facilitate storage and handling. Proper protection, however, is often neglected, and high concentrations of sodium chloride are capable of leaching into the ground, gradually working their way into the water table. As a result, local wells and water supplies located near poorly protected salt piles may be easily contaminated.

The following examples illustrate the results of such negligence. A Michigan report of 1963 found a well located near a Highway Department salt pile contained 4,400 mg/l chlorides (27). This figure is alarmingly above the maximum limit set by the U.S. Department of Public Health of 250 mg/l chlorides for potable water. Dissolved salt had flowed into a broken storm sewer and worked its way into the aquifer which fed the contaminated well.

In Peoria, Illinois, the city salt storage facility was discovered to be the source of serious chloride pollution to industrial water use wells along the Illinois River Valley (27). It is important to note that the limits for chloride for industrial uses is in many cases below the 250 mg/l limit for drinking water (see Table 3). Excessive chloride increases the electrical conductivity of water, rendering it unfit for many industrial processes (27, 83). In Wisconsin, five wells were found to be contaminated by salts resulting from leaching of a stock-pile. Normal chloride levels were around 12 mg/l, and the actual chloride range in the wells was found to be between 19 and 1,345 mg/l (27).

Dumping sites for salt-laden ice and snow can be as severe a local problem as salt storage sites. Barbertown, Ohio, for example, was forced to close its entire municipal well field in 1950 as a result of ground water contamination on the opposite side of the Tuscarawas River by a salt-laden snow disposal area. A level of 20,000 mg/l $CaCl_2$ was found in the water supply (27).

According to Superintendent John F. Eldridge of the Metcalf Middle School in West Greenwich, R.I., rock salt stored by the State Department of Highways near the school's artesian well, permeated the water supply. As a result, the salt caused a flood in the school's boiler room by

corroding holes in the hot water heater. (60)

Highway Runoff Contributing to Groundwater Contamination

The other source of increasing chloride contamination of groundwater is the leaching of salt from highway and road runoff. The salt that is spread on roads dissolves in water and infiltrates into the ground when it leaves the road surface. Unlike the runoff from salt stock-piles, which can be prevented, the runoff from roads would be almost impossible to control without substantial sums of money and re-development programs for road construction. Considerable damage to groundwater supplies has resulted from this road runoff and it is this area which poses the most serious threat to groundwater contamination.

Massachusetts Towns

Chloride levels reached critical levels in the public water supply of Burlington, Massachusetts, which resulted in the institution of a total salt ban. Burlington stopped using salt when the chloride count in one well field reached 272 mg/l, exceeding the Federal limit of 250 mg/l, in July of 1970. There was a five-ten fold increase of chloride in the main station located in the Vine Brook Basin (81). The one year ban has had impressive results on the water supply, and as of Aug. 4, 1971, the chloride level dropped from 272 mg/l to 130 mg/l, although the state had predicted that no substantial difference in chloride levels would occur for five years (14) (see Appendix B). Efforts to have the State stop using salt on State-maintained highways running through Burlington have failed, and large quantities of salt are still being used on Routes 128, 3 and 3A.

The town of Weston, Massachusetts, has had serious problems as a result of chloride contamination of their public water supplies. Since May 1970, Weston has been unable to utilize its water supply. The origin of this chloride is believed to be the salt applied to highways and roads. As a result, the Metropolitan District Commission has been selling water to Weston for public use. (17) In 1963, Tyngsboro and Charlton reported adverse effects from salt such that two wells were condemned by the State Health Department. (35) The town of Springfield encountered a high chloride concentration in public water after the opening in 1958 of the Massachusetts Turnpike which passed through the watershed.

In 1964, the U.S. Geological Survey sampled groundwater along the highways within a 50-mile radius of Boston. Findings showed a large percentage of groundwaters were approaching 250 mg/l chlorides. These chlorides have been steadily increasing each year (27) (see Table 4 and Figure 1).

New Hampshire

The New Hampshire Highway Department started a program in 1953 to replace wells contaminated by chloride runoff from highways and roads. Some wells contained an excess of 3,500 mg/l compared to the natural level of 10 mg/l. Between 1953 and 1964 over 200 wells have been replaced at a total cost of over $200,000. Most of the problems have been associated with hand dug, shallow wells, which have been satisfactorily replaced by wells of drilled construction (27).

Maine

From 1966-1968, Hutchinson conducted surveys on 115 wells located on state highways throughout Maine. Normal sodium and chloride levels were in the range of 3-4 mg/l. Average results for the roadside wells showed sodium and chloride levels around 75 mg/l and 160 mg/l respectively. Hutchinson's contaminated wells were also mainly shallow and hand dug (27).

Salt Free Diets

Last year Massachusetts used more than 200,000 tons of salt plus 6,000 tons of $CaCl_2$ on its highways. The buildup of sodium and chloride in the water supplies of 63 Massachusetts communities has posed a health threat to people on low salt or salt-free diets (16). People with heart trouble or kidney disease, pregnant women, and even people trying to lose weight, have been advised to limit their salt intake (55). Dr. Alfred Frechette, Commissioner of Public Health, circulated a letter to all Massachusetts physicians notifying them of the salt build-up in water supplies in order to forewarn patients with salt-restricted diets. In affected areas, salt is in excess of 20 mg/qt. while limits for some patients are as low as 25-40 mg/qt. per day. The American Heart Association recommends that water containing 22ppm. sodium (59ppm. chloride) should not be used when patients are on diets which restrict the intake of sodium to less than one gram per day. Normal adult intake of sodium is about four grams per day. In his letter, Dr. Frechette pointed to road salt as the reason for the steady increase in sodium and chloride levels in reservoirs and wells since 1945 (12).

Rivers

Salt concentrations in rivers from de-icing chemicals are not a serious problem at present, although contamination is on the increase in several places.

U.S. Public Health Service Data, covering 1958-1963 for six major U.S. rivers - the Delaware at Philadelphia, Pa.; the Hudson below Pough-

TABLE 4

CHLORIDE LEVELS OF MASSACHUSETTS PUBLIC WELL WATER SUPPLIES

	1960	1964	1970
Abington	9 mg/l	19 mg/l	42 mg/l
Acton	9	17	35
Attleboro	6	13	32
Auburn	40	55	110
Avon	9	28	53
Bedford	13	23	37
Billerica	ng	22	39
Braintree	27	64	110
Burlington	10	25	150
Concord	6	9	11
Danvers	ng	16	33
Dedham	12	30	50
Framingham	15	25	99
Lincoln	ng	ng	28
Natick	10	25	75
Needham	11	18	36
Reading	11	35	100
Walpole	7	15	80
Warren	9	15	100
Wellesley	18	25	55
Weston	15	40	160
Weymouth	22	45	60
Wilmington	9	28	70
Woburn	19	45	83

NOTE:

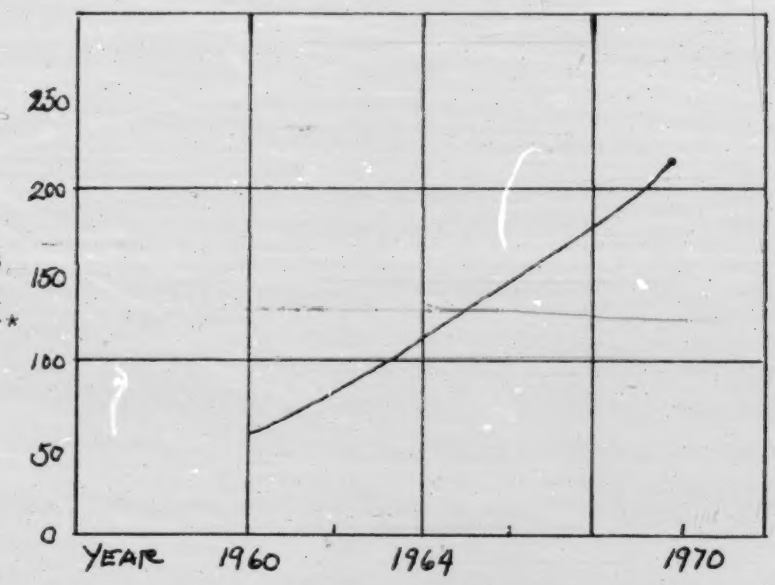
These figures constitute an average chloride count of the total number of groundwater wells in each community. Where no statistics are available, "ng" is used.

SOURCE:

"Public Water Supplies in Massachusetts" 1960, 1964, 1970, Massachusetts Department of Public Health

FIGURE 1

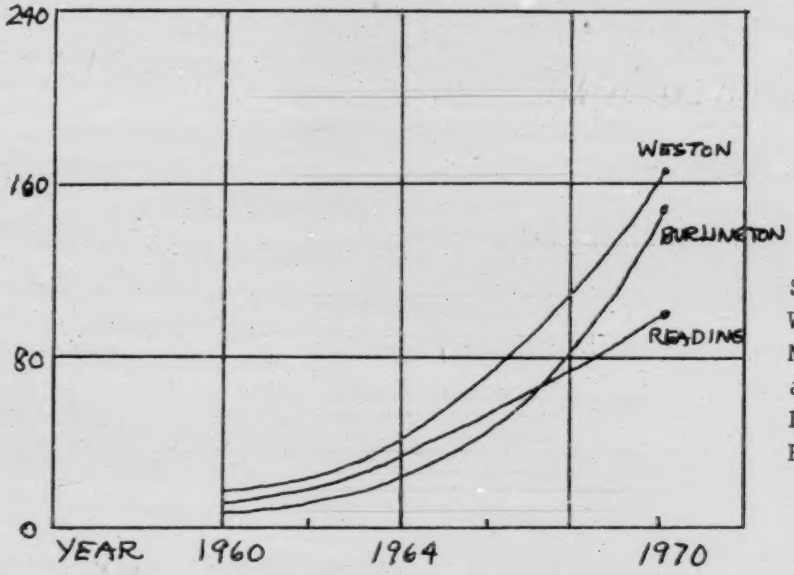
CHLORIDE LEVELS IN WELL WATER SUPPLIES IN SELECTED MASSACHUSETTS TOWNS AND SALT PURCHASED BY MASS. DEPARTMENT OF PUBLIC WORKS



Thousands tons of salt purchased by year*

1960 - 50,183 tons
1964 - 104,183 tons
1970 - 215,000 tons

Source: Mass. Dept. of Public Works and Mass. Legislative Research Bureau. (Ref. 54)



Chloride level (mg/l) of public well water supplies

Source: Public Water Supplies in Mass. 1960, 1964 and 1970. Mass. Dept. of Public Health.

* Total sodium chloride and calcium chloride purchased by Mass. Department of Public Works for use on State highways. State highways comprise 2800 or 10% of the 28,000 miles of road in the State as a whole.

keepsie, N.Y; the Mississippi at East St. Louis, Ill; the Missouri at Kansas City, Kansas; the Ohio at Cairo, Ill.; and the Potomac at Great Falls, Maryland - indicate little problem from de-icing salts. This is due to the volume of water in large rivers, which has so far diluted chlorides sufficiently to prevent any serious problems. In all the rivers except the Ohio, concentration is below 35 mg/l, which is well below the USPH's acceptable chloride level. The Ohio shows great fluctuation, having reached almost 90 mg/l at one point, but there seems to be no cause for alarm from the standpoint of public health, although this level of chloride can jeopardize some industrial processes. Also chloride concentrations are increasing in the Hudson and Delaware and could eventually become dangerously high (36).

In 1966 and 1967 F. E. Hutchinson analyzed seven major rivers in Maine - the Kennebec, the Dennys, the Saco, the Androscoggin, the Penobscot, the Machias and the Narraguagus - for sodium and chloride concentrations. He found insignificant increases (1 mg/l in sparsely settled areas; 15 to 18 mg/l in heavily settled areas) and wrote: "It can be concluded from the results obtained in the first two years of this study that sodium and chloride ion concentration in rivers of Maine are not being seriously affected by salt materials applied to highways for purposes of de-icing," (36) and ". . . it appears that the influence of highway salts . . . is compensated for in the springs, when snow melt is at a maximum, by the increased volume of flow in the rivers" (47).

The Milwaukee Sewerage Commission, in conjunction with a study of chloride levels in the sewage of that city, reported high chloride concentrations (1,510 - 2,730 mg/l, with one value of 200 mg/l) in three rivers, the Kinnickinnic, the Memononee and the Milwaukee, in the metropolitan area on January 16, 1969. "The large majority of chlorides . . . is believed directly attributable to de-icing salts placed on the streets and highways in the Milwaukee area." (27)

Ponds and Lakes

Ponds and lakes also receive their share of salt pollution with potentially more serious consequences.

F. E. Hutchinson of the University of Maine studied 27 roadside farm ponds in Maine in April, July and August of 1966-68. He found significantly higher sodium and chloride levels in April, the time of runoff from melted snow, and significantly higher overall chloride levels for these ponds as compared to others in the same area. (Average chloride values for the roadside ponds were 110 mg/l for April and 80 mg/l for August. Normal values are 5-10 mg/l.) He concluded that road salting is an important factor in both seasonal and yearly-increasing salt levels in the ponds. (27)

Studies by Ownbey and Kee on Lake Erie (1967) indicate that the average chloride content has tripled over the last 50 years (36). Although the present level (23 mg/l) does not affect water usage at present, continuing increases in the lake could bode trouble, especially for industrial uses of lake water. Of the annual amount of chlorides entering the lake, 11% (750,000 tons) comes from road salt. Salt tonnages entering the other Great Lakes are: Superior, 91,000; Michigan, 438,000 tons; Huron, 198,000 tons; Ontario, 525,000 tons (27).

Lake Wingra, one of the lakes in the Madison, Wisconsin area studied by the Madison Rivers and Lakes Commission, quadrupled its chloride levels from 1959-1965 (9-11 mg/l to 41-43 mg/l) (27, 36, 39).

At Cumberland, Wisconsin, 1959 research on Beaver Dam Lake showed chloride concentrations increasing with depth, ranging from 8 mg/l near the top to 33 mg/l near the bottom (27). More severe cases of this density stratification have prevented vertical mixing in some bodies (see below) thereby causing a lack of dissolved oxygen at lower levels, with consequent detrimental effect on plants and fish.

J. H. Judd studied salt runoff in 25-foot deep First Sister Lake in a suburban section of Ann Arbor, Michigan, in 1965-68. He found density stratification (150 mg/l chloride at 23 feet; 60-85 mg/l near the top), due to road salting, that prevented complete spring mixing of the waters. Complete fall mixing might also have been prevented, except that some of the salts were taken into the lake bottom during the summer. This lack of mixing prevented oxygen from reaching the lower levels of the lake, and caused some damage to plant and animal life (27, 49); ". . . the deeper zones of the lake were likely without oxygen for some ten months, and the entire lake below the 10-foot depth was virtually devoid of dissolved oxygen for about eight months (27).

Diment and Bubeck studied Irondequoit Bay in Rochester, New York, in 1969-70, where winter road salt is the "single major source" (27) of salt in the waters. The bay showed a density stratification of its waters sufficient to prevent their vertical mixing in the spring, an unusual occurrence for a body so large (3.7 miles long, one mile wide) and shallow (average depth 24 feet, maximum depth 75 feet). This stratification also delayed salt mixing for one month, as compared with 1939-40 (49). Dissolved oxygen from January-November 1970, the period of severe stratification, was, at maximum, 1 mg/l. Average surface water chlorides were 160 mg/l; average bottom water chlorides were 220-400 mg/l. Although the situation is not currently alarming, salt has seriously changed the Bay's characteristics, and it should be carefully watched. Needless to say, such situations could also occur elsewhere (20, 27).

Conclusion

The most serious problem at present from salt pollution of water resources is contamination of groundwater and public water supplies. This is amply demonstrated by events in the Massachusetts towns of Burlington and Weston. Lake concentrations of salt are on the increase, which could pose a threat to fish populations and to industrial use of water; this threat could also apply to rivers and streams. Given the increasing popularity of salt as a de-icing chemical, these problems are almost certain to become worse.

VI. VEGETATION

Introduction

De-icing salts removed from the road by surface runoff eventually either wash into streams or infiltrate the soil bordering the roadway. Once in the soil, salt can have damaging effects upon both the soil structure and the vegetation dependent upon it for growth. A substantial amount of literature is available on the effects of salt on plant life, but nearly all of this concerns agricultural crops in arid regions (38). Within the past ten years, however, several studies have focused on the effects of de-icing salts on roadside vegetation.

The three most common constituents of de-icing salts, sodium, chloride and calcium are naturally present in most northern soils. Calcium is essential to the growth and development of all plants. Some and perhaps all plants require trace amounts of chloride. Salt is only essential for a few plants but benefits many. Under natural conditions, then, these elements have no adverse effects (80).

High concentrations of these salt ions can have direct toxic effects on plants and contribute to injury in a number of indirect ways.

Effects of De-Icing Salts on Soil

Prior and Berthouex (59) studied the movement and accumulation of salts in roadside soils of Connecticut. Soils were sampled at the surface, 1-,2-, and 3-foot depths and at distances of 5, 25, 50 and 100 feet from the highway. Greatest salt concentrations were found near the highway and close to the surface. In a number of cases, salt was shown as travelling more than 100 feet laterally from the highway, but the predominant movement was downward. Salts were significantly higher within the soils in January-February than in other months. Salts were readily leached out of the upper few feet of soil and by April the majority of salts were displaced downward. By fall, minimal levels of salt remained. A study of sodium and calcium levels in roadside soils in Maine (Hutchinson, cited in 27) showed a strong correlation between the consecutive number of years of salting vs. the increasing levels of sodium and calcium ions in adjacent roadside soils. From a total of 22 locations, samples were collected at 0, 30 and 60 feet. Sodium values averaged 281, 139 and 96 ppm re-

spectively. Associated calcium values were 116, 79 and 54 ppm. Sodium and calcium content of roadside soils were 6 and 115 times higher than normal for Maine soils. There is, then, a definite possibility that salts can accumulate over the years in some soils.

Directions and rates of salt movement within the soil will depend, of course, on a variety of factors: whether the soil is frozen or not; amount and patterns of rainfall; depth to water table; soil texture, structure, chemistry and organic-matter content; the resulting permeability and cation exchange capacity; the types and density of soil biota; and so forth. By and large, it is the relative abundance of rainfall in the northern states resulting in rapid leaching of salt from the soil that has thus far provided a natural solution to the salt problem as it affects vegetation (80).

The sodium ion (Na^+) is important because it can change the character of the soil. Cations are absorbed onto soil particles and maintained in equilibrium with cations in the surrounding soil water. If sodium salts are applied to the soil, the equilibrium is changed whereby sodium ions replace calcium ions on the soil grains (27). When sodium comes to occupy more than about 15% of the total cation exchange capacity of the soil, soil structure begins to deteriorate. Such a "sodic" soil loses its ability to remain sufficiently aggregated and its permeability and water holding capacity decrease markedly. The resulting excess surface runoff and diminished aeration provide dismal conditions for the growth of many plants. An exchangeable sodium level of 17% has been reported for the soil along a major highway in Maine following 18 winters of salting (80). Neither the chloride nor the calcium ions from road salt appear to have an adverse effect on the soil itself (59,80).

Effects of De-Icing Salts on Plants

All three ions, however, contribute to the total salinity of soil water and thereby exert an effect on plants. Salinity causes interference with the mechanism whereby a plant absorbs moisture from the soil. Soil water enters the plant root through a membrane across which an osmotic pressure differential is maintained. The flow of water through the membrane is in the direction of higher salt concentration and, therefore, increasing salinity in the soil makes it more difficult for water to be taken in by the plant. Besides short-term damage caused by saline soils, some data show that low salinities over extended periods can cause cumulative damage (27). It is clear that the

adverse effects of salinity reinforce those of water stress (drought) and vice versa, and in nature the syndromes of the two can be difficult to separate (80).

Another effect of de-icing salts on vegetation is toxicity of specific ions within plant tissues. Uptake of salt ions is largely by root absorption, but leaves and shoots can also take in ions. The actual mechanisms of transport, accumulation and injury are not well understood (80). That uptake of sodium and calcium is at least partially independent, is indicated by the data of several studies (22, 43, 45).

Chloride has been found to exert a toxic effect on plants. Excessive chloride is evidenced by its accumulation in the leaves and causing leaf burn (59) and shoot-tip die-back particularly in woody plants (80).

When an excess of sodium accumulates within a plant, the first outward effect may be a deeper green color in the leaves. Under somewhat more aggravated conditions, the tips or margins of the leaves of many species die and abscise sooner than normal (80).

Hyper-calcium toxicity is rare (80) and has not been reported as an effect of de-icing salts.

Excess salts can also lead to nutrient deficiencies in some plants (80). Data indicate that sodium, possible through ion antagonism, has suppressed the uptake of potassium, calcium, magnesium, all essential nutrients. It is also possible that the presence of chloride ions depresses the uptake of nutrient ions (22).

There is considerable agreement that salt can kill roadside vegetation (42,43,44,45,56,78,80). The most significant question to ask is whether the amounts of de-icing salts used in actual practice are detrimental to roadside plants.

An investigation of 550 roadside maples in New Hampshire (Lacasse and Rich (52)) showed that maple decline, apparently due to severe salt injury, is limited to the immediate roadside and its drainage area. Higher than normal sodium levels were recovered from leaves and twigs of trees growing within the windrow of plowed snow. Soluble salts in maple sap were also higher than normal in this area. No disease causing organisms were consistently found.

Holmes (44) reported that salt application to roads in Massachusetts was not the primary cause of illness to roadside trees. No symptoms of salt injury observed on any of the trees in run-off plots after 7 winters of salt applications to adjacent road surfaces, but trees with weekly applications of salt throughout the year had chlorotic foliage with necrotic margins. In a later study (45) Holmes concluded that there was not a basic conflict between the work of Lacasse and Rich (52) and his earlier work (44). Actually, both investigations showed that salt can and does injure sugar maples under certain circumstances but not under others.

A survey of 142 maples along New Hampshire highways (Kotheimir, Niblett and Rich (50)) indicated that trees along salted State roads are much less vigorous than trees along unsalted town roads. Since the trees were growing under comparable climatic and other environmental conditions, it was concluded that highway salt plays a role in their deterioration.

Following the relatively severe winter of 1966-67 in the Washington, D.C. area, Wester and Cohen (79) found severe salt damage to vegetation. The effects of heavy winter-time salting were compounded by a serious lack of rainfall in April, 1967, which provided little opportunity for natural leaching of salts from the root zone.

In a study of roadside sugar maples in Connecticut, Button and Peaslee (22) reported that there are detrimental effects of chloride de-icing salts on roadside sugar maples. Tissue concentrations of sodium and chloride increase with increasing exposure to roadside drainage and that exposed trees generally exhibit more severe symptoms of declining vigor and contain lower concentrations of some essential nutrients in their tissue.

Experiments by Walton (78) show that salt is phytotoxic to Norway Maples at rates comparable to those used by the Connecticut Highway Department. The similarity of the curves of symptom expression and chloride content of the foliage is quite apparent.

Most reports have considered movement of salt from the road to be through the soil water and into plants through their roots. Hofstra and Hall (41) have concluded from field observations in Ontario that sodium chloride is whipped up in a spray by traffic and blown into vegetation, contributing to severe foliage damage of white cedar and several species of pine up to 120 meters from the road.

Although a significant amount of injury to vegetation by de-icing salts is the result of such indirect effects as impaired root aeration, water deficiency and nutrient imbalance, additional troubles result from spray and internal accumulation of chlorine and sodium ions. The overall effect most likely to occur first is a growth depression, then leaf burn followed by shoot die-back, and, if sufficiently severe, eventual death. Which aspects of the salt syndrome are primarily the result of indirect effects and which of specific ion toxicities is not easy to separate (80). Finally, the damaging effects of salts may not become apparent for several years (22,27). Sub-lethal salt doses may cause plants to become more generally susceptible to disease, and salt changes in soils and vegetation may more subtly, but more importantly, be affecting entire natural ecosystems.

Different species of plants range from highly salt-sensitive to highly salt-tolerant. Trees and woody plants are in general more sensitive than herbaceous plants, particularly grasses (80). Some studies show grass mortality due to de-icing salts (22,39, 42,79) but some highly tolerant species have been identified (39). Shortle and Rich (69) estimated the sodium chloride tolerance of 22 species of roadside trees from New Hampshire field data. Salt-tolerant species include: red oak, white oak, red cedar, black locust, quaking aspen, black birch, paper birch, gray birch, yellow birch, black cherry, white ash, large toothed aspen; intolerant species include: bosswood, shagbark hickory, American elm, red maple, white pine, ironwood, hemlock, sugar maple, speckled alder, and red pine.

In recent years, students of plant diseases have been finding that they must move away from the old days of studying single causes for ill health in plants (43). Many factors have been suggested as contributing to the decline of roadside trees including soil compaction, air pollution and drought (Banfield, cited in 78), and each additional form of stress has a synergistic effect when combined with other forms. De-icing salts, therefore, can be considered more damaging, rather than less so, because they constitute an added burden to trees already under the accumulated stresses of the harsh roadside environment.

Corrective Measures and Economic Considerations

The most effective measure for preventing salt damage to vegetation is to keep salt away from plants. Careful application procedures and highway design incorporating ditches to collect runoff are recommended. Salting could be eliminated late in the

season when plant growth will begin before the salts can be leached out of the root zone.

Once the salt is in the soil it could be leached out by watering. This has been suggested along with rinsing of evergreen foliage as a measure for home owners when there is a dry spring (72). Addition of fertilizer strengthens plants generally and replaces nutrients that leach out. Application of soil amendments including various forms of calcium to counteract the effects of salt has been suggested (80). Another approach is to replace dead vegetation with new plantings of salt-tolerant species.

All of these corrective measures involve considerable expense. Collection of runoff creates the expensive problem of treatment and disposal. The International Shade Tree Conference (48) has developed a dollar value formula for shade trees widely used for insurance and damage appraisals. Prominently placed desirable species in perfect condition are valued at $9 per square inch at 4½ feet above the ground. A 12-inch diameter tree = $1,018, and a 24-inch diameter tree = $4,072. In 1962 the town of Winchester, Massachusetts, reported no dead maples. Then, in 1963, increasing winter salt use and 2 dry summers combined to make the number of dead maples jump from zero to 66. Since then, the number has remained high, averaging 56 dead non-elms and 49 dead elms removed every year by the town from between the sidewalks and streets. In 1969, the cost of 200 small trees was $2500 plus a week's labor for three men to plant them. Much more, $8,000 a year, was paid to a contractor to remove some of the dead and dying trees, and still more in labor costs for tree removal by town employees. Although many of the trees have been replaced, the replacements are small trees, while the dead trees were giants. These losses due to salt reduce the property values in the town, generally, by considerably more than $100,000 per year (more than $15/house/year). Costs of damaged grass and shrubs are also to be considered (73). While the costs may be attributed to aiding automobile owners, those costs are borne by landowners both as intangible losses of amenities and as economic losses in property values and property taxes devoted to tree removal and replacement.

Conclusion

The only measure that does not entail the considerable economic costs of collecting runoff, planting tolerant species, etc., or the intangible, aesthetic costs of unhealthy vegetation is to reduce the use of de-icing salts. That there are many factors contributing to the decline of roadside vegetation is not in question. But, the argument that we can therefore do nothing is not valid because the use of salt is one factor that can be controlled.

VII. WILDLIFE

Evidence for effects of de-icing salt on wildlife is scarce and inconclusive. According to the National Technical Advisory Committee to the Secretary of the Interior, "salinity may have a twofold effect on wildlife: a direct one affecting the body processes of the species involved and an indirect one altering the environment, making living or species perpetuation difficult or impossible," (36). The latter effect would seem to apply at present to fish, the former to land animals. Salt affects mammals through ingestion, and fish by interfering with the animals' osmotic balance. It can also degrade fish environments in lakes by causing, through density stratification (see above), a lack of dissolved oxygen at lower levels, and it can also have "deleterious effects on fish food organisms," (36).

Certain types of fish (euryhaline) can live in either fresh or salt water, and some others (anadromous) can withstand sharp changes in salinity over a short time period. Salt water fish also have a less difficult time acclimating themselves to fresh water than do fresh water fish acclimating to salt. The harmful and lethal effects of salt on freshwater fish are due to the raised osmotic pressure on the gills, which results from the higher salt concentrations in their aqueous environment.

Hanes et.al. (36) reviewed the literature on fish and found that the number of parts per million of NaCl or $CaCl_2$ required to harm or kill fish is generally in the thousands (with the range given 400-50,000 ppm), a situation that is at present only frequently approximated in direct highway runoff and discharges from industrial plants (39). In Irondequoit Bay in Rochester, New York, however, the salt concentrations near the bottom have run as high as 400 mg/l (see above). This closely approaches harmful levels, and as pollution in large bodies is extremely difficult to reverse once it is well started, the situation should be carefully watched.

Salt's additives may be as great a danger to wildlife, especially fish, as salt itself. Sodium ferrocyanide, an anti-caking agent, releases poisonous cyanide ions upon decomposition. Sodium hexametaphosphate, an ingredient in a certain rust inhibitor, can serve as an additional source of phosphorus in eutrophication, which degrades fish environments (36). Sodium ferrocyanide is used in salt in Massachusetts, as is ferric ferrocyanide, which, however, is more stable than its sodium counterpart and appears not to injure fish (27, phone call to Mass. Department of Public Works . . . . Feb, 1972).

It seems that fish, through contamination of their habitats, are in more danger than mammals from salt and salt additive pollution, but more research needs to be done, especially in the field; meanwhile, the dangers to both should not be overlooked.

VIII. THE EFFECTIVENESS OF SALTING

A majority of the literature reviewed refers to de-icing salt, and the "bare pavement maintenance" associated with it (63, 64), as providing the highest degree of safety and convenience to motorists of all snow and ice control methods available to local and state agencies. The connection between salt and safety is in most cases considered axiomatic, so that any comparative analysis between salting and other snow control methods automatically stresses safety as the innate advantage of salting. There appears, however, to be little statistical evidence either to substantiate or to disprove the connection, although attempts have been made to do each. In fact the hypothesis has been offered by some critics of salting (83) that de-icing salts may increase rather than reduce driving hazards, although again statistical evidence is scarce and by no means conclusive.

An analysis of statistical data on accidents and weather conditions may be severely hampered by their being incomplete in scope. The Massachusetts Registry of Motor Vehicles, for example, lists accidents according to road surface conditions classified under five categories: "dry", "wet", "icy","snowy", or "other." Intermediate conditions or, more importantly, mixes of conditions (such as might be created by salting) are not described and the categories appear general at best. Also, the type and degree of snow and ice control (e.g.,salting versus plowing versus none) do not appear in state accident records, and must be supplied by the researcher in other ways.

One 1971 study,by Arvai (10) provides at least some useful data, if no conclusions,on the relationship between de-icing salts and accident rates. Analyzing two sets of accident files (selected Michigan counties and selected Oakland County, Michigan, cities), Arvai arrives at two apparently contradictory results. He finds that with increased usage of salt, the percentage of accidents occurring under icy conditions <u>decreased</u>; but at the same time, with increased usage of salt, there occurred an <u>increase</u> in the total number of winter accidents (i.e.,including accidents under icy road conditions as well as accidents under bare pavement conditions). One explanation for this apparent contradiction may lie in the manner in which accidents are statistically recorded. If, for example, road conditions were generally icy (or ice-prone), but salt were applied so as to melt ice, accidents may be recorded as occurring on "dry" or "wet" pavement, rather than on "snowy" or "icy" pavement.

Another explanation might be that salt has positive effects (i.e., lowering accident rates) under the immediate icy road conditions when it is applied, but "residual" negative effects (raising the accident rate) when it is on clear roads, but not needed to melt ice. Several explanations for such negative effects of salt on clear roads have been suggested. Critics of salting (83) note that "bare pavement" cleared of snow and ice by salt may actually maintain a thin, slippery film, created by the remaining salt's attracting or retaining moisture, which represents a hidden hazard to traffic. Motorists, they contend, may be given a "false sense of security" (10, 83) by the pavement which appears to be as dry and safe as dry, unsalted summer pavements, leading them to increase speed and drive with less care. Also salt spray can create a semi-opaque, white film on the windshield which can substantially reduce visibility and may contribute to accidents in this way (10, 33, 83).

Other than the Arvai study, there appears to be no other reliable data available on the relationship between de-icing salts and accident rates. Burlington, Massachusetts, which discontinued road salting in 1970, experienced a reduction in total accidents from 1061 in 1969 to 989 in 1970 according to the Burlington Traffic Division (83), although a two year sample is too small to be statistically significant. Dr. Julian A. Waller, Professor of Community Medicine at the University of Vermont, and head of a highway safety testing program in Vermont, describes "a frustrating literature search" in conjunction with the Federal Highway Administration, in which several hundred papers concerning salting practice and methods were found, but only one concerning the rationale behind salting. In literature published by the industry's Salt Institute to support the connection between salting and highway safety, Waller found a disturbing amount of "statistical juggling" (84). Waller does note, however, that "it is of much more than passing interest that according to Accident Facts (National Safety Council) from 1956 to 1970 there has been no change in the proportion of all crashes, injury crashes and fatal crashes that occurred on roads covered with snow and ice despite the fact that since 1966 the total usage of salt has increased several fold in the 33 states that carry out salting. On the basis of this research to date, Waller concludes that "any assumption that salting increases safety in winter driving is highly premature".

Conclusion

The overall effectiveness of salting in providing the safest possible winter driving conditions appears to be an unsettled question, which must await the results of further research before it can be resolved. It does not, however, appear to be necessarily in the public interest to accept, without question, the assurances of the salt industry that salting is equivalent to safety.

IX. ALTERNATIVES

If de-icing salts were to decline in use, for reasons of environmental damage or questionable effectiveness in providing safe winter driving conditions, a snow and ice control program restricting or eliminating salts would have to be developed. In formulating such a program it would be helpful to view the problem as a combination of a number of variables interacting to create hazardous and inconvenient roads. Grouping these variables under component headings we might have (1) snow and ice; (2) the automobile; (3) the roadway; and (4) the driver, each of which can be treated, designed or otherwise manipulated to affect, in some way, the status of the problem. In any snow and ice control program accurate weather prediction and monitoring of road conditions will play an important role. Snow can be either melted, moved, or left on the road, and a number of alternative approaches are discussed below.

Snow Treatment - Chemical Alternatives to Salt

Adrian Clary of the Highway Research Board (25) lists five criteria for the ideal de-icing agent: it must (1) effectively melt ice, frost and snow at low cost; and it must not (2) create a slippery pavement surface; (3) damage air-entrained concrete; (4) corrode steel; or (5) be toxic or degrade the environment. A number of chemicals have been tested to date, but none (including salt) meet these criteria. Urea costs twenty times as much as salt and creates a paste-like slippery substance when it melts (15). Nitrate of soda, a fertilizer, is effective, though much more expensive than salt, and may contribute seriously to eutrophication (43). In addition various chlorides such as magnesium, potassium, aluminum and lithium chloride, and ammonium acetate, methyl and ethyl alcohol, isopropyl alcohol glycerol, aldol, mixed amides and chemical dyes have been cited as possible chemical de-icers. These are all less economical than salts and most have undesirable environmental side effects. Some are more toxic than salts; some increase corrosion, others have a eutrophication potential or are hazardous to handle (27). The Highway Research Board recommends a composite de-icing agent of urea and calcium formate, although the effects of this mixture on the environment (other than highway structures) is not discussed in their report (13).

Snow Treatment - Abrasives

In the past, highway maintenance departments generally depended heavily on abrasives in their snow treatment programs. There is no temperature barrier in their effectiveness as there

is with salts. They are used to increase traction and are most effective on hard packed snow or icy surfaces. The major disadvantage of abrasives are that they have no snow melting properties, and they have to be continually applied during a storm, because when they are covered by snow, or ground in by traffic, they are ineffective. They also tend to be blown off the road easily if not mixed with salt or ethylene glycol (both of which bond sand to the road surface) (7). A spring cleanup to remove abrasives from roadsides, catch basins and drains adds to the cost.

Sand, the most common abrasive, is comparatively inexpensive and does not damage roadside vegetation. It can also be re-used either on roads or for landfill operations. After sand has been applied to the roads and driven over for a full season, it becomes too polished or ground down and is no longer effective for traction, and therefore cannot be re-used for road maintenance purposes. In addition to sand, granite chips, limestone, other crushed stone, and even "kitty litter" have been suggested, although these are economically unfeasible by comparison.

Snow Treatment - Types of Equipment

Because winter road conditions vary widely according to depth of snowfall, temperature, amount of traffic and so forth, the kind of equipment available for snow control work must be versatile. Different, interchangeable attachments are available which can easily be mounted to the basic equipment in anticipation of changing conditions. A front-end loader can be used with either a bucket attachment or a snow-blower (2). The blower works efficiently in removing snow from busy streets, and needs only one traffic lane, while a bucket attachment can break through a deep snow drift. Rubber plow blades, more expensive initially but more durable than steel blades, prevent operator injury and equipment damage by riding smoothly over obstructions. They are not effective, however, in removing hardpacked snow or ice from roads and tend to act as a brake when they hit dry pavement. Rubber blades (31) are best for removing dry or very slushy snow and under the right conditions, can clear down to bare pavement. Steel blades can be improved by using tungsten carbide tips (28) for longer wear and spring loaded (29) or reverse bent blades (32) to allow more flexibility over obstructions. Melters, both mobile (85) and stationary (53), are useful in large cities where there is a problem with snow storage or disposal.

Road Design and Maintenance

A number of principles and techniques of road design have been developed which can reduce winter road maintenance problems

and increase winter highway safety. Among these mentioned in the literature are snow fences, snow walls (40), insulated bridge decks (6), road condition monitors (5), non-skid pavement (8, 67, 70), and heated pavements (40). Electrical resistance heating coils located under the pavement surface are probably the most effective and safe method of snow removal but the high power demand makes them uneconomical in general use.

The geometric standards governing highway design are based upon speed limits which are expected to be maintained under dry pavement conditions. It would appear that one variable in traffic safety which would be easily adjusted on a daily basis is the posted speed limit. Given certain adverse snow and ice conditions, the alternatives open to authorities with respect to traffic control would be either to maintain the dry pavement road conditions as well as possible while holding speed limits constant, or to accept some reduction in road safety due to snow and ice (and perhaps salt) and reduce posted speed limits (and enforce them) accordingly. The trade-off will essentially involve driver time versus highway safety.

Driver Education and Automobile Design

The two components of the winter driving problem, in addition to the "imposed" snow and the roadway itself, are the automobile and the driver. While there has been relatively less effort to influence these elements toward a safer winter driving situation, the possibilities should be noted. Automobiles equipped with various types of snow tires and chains, as well as vehicles designed with four-wheel drive, front-wheel drive, or engines located in the rear show substantially better performance on snow and ice, although rear-engine vehicles can be more dangerous in skids. Public education to acquaint drivers with the particular characteristics of winter driving would tend to reduce human error, a crucial element in highway accidents.

Management

Whatever program is instituted to reduce or replace salt use for snow control, management will play an essential role in its success. In Burlington, Massachusetts, which banned salt in 1970, management became one of the most serious problems in converting to a non-salt maintenance program, according to Richard Brown, Executive Secretary to the Board of Selectmen. Highway crews, used to relying on de-icing salts, must be re-educated in order to be familiar with new equipment, routes, timing, and methods. Because a sanding program requires more on-line labor and effort than a salting program, Burlington experienced some resistance among maintenance crews in effecting the conversion to sand.

X. ECONOMICS OF SALTING

Although the literature reveals a number of references to the costs associated with de-icing salts, there is no instance where a thorough economic analysis is attempted. Yet, if there are to be rational decisions made as to the use of salt versus another form of snow and ice control, the most conveniently established basis for that decision will be economic. The types of costs accruing to snow and ice control fall into two classifications: direct costs, those directly attributable to road maintenance, e.g., materials, equipment and labor; and indirect costs, those having impact on the larger community. Assessments of the first order of costs are relatively straightforward because all are apparent, and all are easily translatable into dollar terms. Whittle (83) cites snow control figures from Burlington, Massachusetts, comparing winter 1969-1970, when salt was used, and winter 1970-71, when only sand was used (See Table 5). The comparison ($122,229.93 vs. $95,761.82) shows that Burlington reduced snow and ice control costs by over $26,000 during the switchover period, despite added clean-up costs in the spring. It should be noted, however, that these figures represent a period of only two years of varying weather conditions. According to Richard Brown, Executive Secretary to the Burlington Board of Selectmen (in private conversation January, 1971), "No two storms are alike," and each offers unique problems of snow and ice control which are difficult to predict in terms of labor and materials costs.

The inclusion of indirect costs into the formulation introduces several problems: defining limits for the analysis (i.e., selecting which costs to include or exclude), assessing the magnitude of specific costs with some degree of accuracy, and translating those costs into comparable terms, e.g., dollars. Several studies exist which treat various combinations of possible indirect costs, although all are hampered by being incomplete, or by making certain assumptions of questionable validity. Hopt (46) provides detailed analysis of comparative costs of a complete sanding program and a complete salting program for Idaho State Highways. Framed as a benefit-cost analysis, it includes all direct costs and adds a low estimate for corrosion ($5 per year per vehicle) and property damage due to accidents. Sand was calculated to reduce accidents by 60 per cent, and salt by 75 per cent; on the basis the assumption (questionable in light of known accident figures) that salt provided better accident prevention because of faster application time and better traction. Even so, salting was estimated to have a benefit-cost ration of 0.25, while sanding was estimated at 2.81, a sizable difference favoring sand. It is interesting to note that the estimate for corrosion damage

of $3,150,000 has the effect of reducing the benefit-cost ratio for salting from 10.25 to 0.25 on the basis of only $5 per year per vehicle. If, instead of this lower corrosion cost, the Society of Automotive Engineers figure of $100 per year per vehicle is used, the corrosion damage estimate rises to approximately $63,080,000, and the benefit-cost ratio shrinks to 0.013.

Table 5

Burlington, Massachusetts, Snow and Ice Control Costs

	Winter, 1969-1970	Winter, 1970-1971
Sand	$13,864.12	$26,708.84
Salt	52,514.51	Not Used
Parts-Repairs	8,461.23	21,111.40
Contractors	41,939.31	32,017.58
Misc.	3,111.76	1,950.00
	$119,880.93	$81,787.82
Sweeping Sand	2,349.00	13,974.00
TOTAL	$122,229.93	$95,761.82

Two other studies, cited by the Massachusetts Legislative Research Council (54), attempt to measure indirect costs to the urban-industrial system. A 1957 study of an average of eight winter storms occurring annually in New York City, estimated annual losses to the economic system resulting from a one hour transportation delay per storm totalling over $30 million. Factors considered were perishable foods, heating fuels, refuse collection, fire losses, and physicians' and ambulance emergency home calls. Before these figures could be meaningfully applied to an economic assessment of salt, some calculation would have to be made of the actual transportation time savings gained by salt use, if any, compared to other snow removal methods, under specific conditions. A Detroit Public Works Department study of local economic losses eliminated by the use of de-icing salts to clear streets during 35 storms, included work losses due to late arrivals, loss to cartage companies, business losses due to reduced consumer sales, and public transportation loss. Some of these items appear questionable on economic grounds, (i.e., consumer sales which were probably delayed but not prevented by the storms) and some comparison between salting and other methods of

snow removal would be useful. A third study cited by the Massachusetts Legislative Research Council (54) suggests gasoline revenues from increased use of roads as a possible benefit to be included in an economic analysis, although this would appear to be stretching the reasonable limits of a snow control study; if gasoline revenues are included as a benefit, should not air pollution appear as a cost?

Two studies on the use of de-icing salts in Winchester (73) and Newton (83), Massachusetts, focus on the indirect costs of salting to the local residents. Southworth et al (73) lists the following costs: damage to shoe leather $2-$20 per person; corrosion $10-$200 per vehicle; tree damage $15-$50 per house; damage to grass and shrubs ($10-$100 per house; plus unspecified costs for veterinary fees (injury to pets), damage to private concrete walks and driveways, and damage to town-owned storm drains. According to a formula developed by the International Shade Tree Conference (48, See Section VI), a select tree might be valued within a range of $1000 to $5000. Accordingly, if a town loses 100 trees per year due to salt damage, as have some towns in Massachusetts (73, 83), damage costs might range upwards from $100,000 exclusive of removal and replacement costs.

Other costs related to salting which have not been documented might be suggested: corrosion damage to water-dependent industrial equipment; bottled water for individuals on salt-free diets who must avoid salt-contaminated public water supplies; conversion costs to towns with salt-contaminated water (new wells, desalination, imported water, etc.); increased maintenance of deteriorated bridge decks; research and development costs by the automobile and concrete industries to find methods to counteract salt-related corrosion and deterioration damage; and so forth. As the nature of the costs extends beyond the immediate field of snow and ice control, the difficulty of assessing the magnitude and of apportioning these costs increases. Certain costs, perhaps more closely related, are difficult to measure in dollar terms once they have been estimated. For example, the dollar value of a person's travel time must be an arbitrary figure, and the dollar cost of human suffering, injury or death is likewise inestimable, unless arbitrary amounts developed by insurance companies are to be considered acceptable. Damage to the natural environment is similarly intangible and especially difficult to measure economically if it occurs as a cumulative process, as soil and water contamination do.

The complexity of the problem suggests that any economic analysis of road salt will approach the vague, unless certain limits are arbitrarily set. And yet, to be complete, any evaluation

should include as many relevant factors as are appropriate to the nature of the problem. Perhaps relying on several common denominators for comparison, e.g., dollars plus human lives plus human time, would be a workable approach. Although it is beyond the scope of this paper to attempt such an analysis, it is appropriate to suggest the importance of including as many relevant factors as feasible in order to arrive at a satisfactory benefit-cost ratio. All analyses reviewed to date, whether favoring salt or opposing it, suffer for allowing substantial omissions. Even if costs cannot be measured, they should be cited as intangibles, and judged according to the values of the decision makers.

REFERENCES

1. Adams, Franklin S., "Salt - Assisted Accidents - A Question of Relative Safety," Street Salting Urban Water Quality Workshop, SUNY Water Resources Center, Syracuse University, Syracuse, N. Y., May 6, 1971.

2. American City, "Blower Solves Both Urban and Rural Problems," and "Snowmobiles vs. Serpentine Street," Jan. 1969.

3. American City, "Chemical Corrosion Argument Rekindled at Snow Conference," June, 1967.

4. American City, "How to Provide Scale-Resistant Concrete," August, 1971.

5. American City, "Ice-Detector System Can Protect Bridges and Runways," Dec. 1968.

6. American City, "Research Target: Slippery Bridge Decks," Jan., 1965.

7. American City, "Treated Sand Keeps 'em Flying," and "Snow Melting by Contract," Dec., 1968.

8. American Public Works Association, "Water Pollution Aspects of Urban Runoff," Final Report on the Causes and Remedies of Water Pollution from Surface Drainage of Urban Areas - Research Project No. 120, conducted for the Federal Water Quality Administration, Jan. 1969.

9. Ammon, Henry, "How to Keep the Snow-Plows Moving," American City, Feb., 1970.

10. Arvai, Ernest S., "The Effect of Salt on the Number of Winter Accidents," HIT LAB Reports, University of Michigan, Highway Safety Research Institute, Jan. 1971.

11. Automobile Industries, "Calcium Chloride versus Sodium Chloride, February 1, 1964.

12. Black, Herbert, "Salt Build-up in Drinking Water a Danger to Some Bay Staters," Boston Globe, May 8, 1970.

13. Boises, David B., et al., "Economical and Effective De-icing Agents for Use on Highway Structures," National Cooperative Highway Research Program Report No. 19, Highway Research Board, National Academy of Sciences, Washington, D.C., 1965.

14. Boston Globe, "Burlington Salt Ban Aids Water," Aug. 20, 1971.

15. Boston Globe, "Conservationists Wary of Salted Vt. Roads", Dec. 13, 1970.

16. Boston Globe, "Salt Seeping Onto More Water Tables," Aug. 1, 1971.

17. Boston Herald, "Road Salt Curb Urged in Charles Watershed," July 7, 1971.

18. Brockton Daily Enterprise, "Norwell to Conduct Tests on Amount of Salt Seepage into Well Fields," April 21, 1971.

19. Broecker, W.S., et al., "Road Salt as an Urban Tracer," Street Salting Urban Water Quality Workshop, SUNY Water Resources Center, Syracuse University, Syracuse, N.Y., May 6, 1971.

20. Bubeck, Robert C., et al., "Runoff of De-icing Salt: Effect on Irondequoit Bay, Rochester, New York," Science, Vol. 172, June 11, 1971.

21. Free Press, Burlington, Vt., "State Environmental Board Issues Compromise Order on Salt Stockpile," Nov. 6, 1970.

22. Button, E.F., et al., "The Effect of Rock Salt Upon Roadside Sugar Maples in Connecticut," Highway Research Record, No. 161, Highway Research Board, National Research Council, National Academy of Sciences, Washington, D.C., 1967.

23. Callahan, Joseph P., et al., "Effect of Stress on Freeze-Thaw Durability of Concrete Bridge Decks," National Cooperative Highway Research Program Report No. 101, Highway Research Board, National Research Council, National Academy of Sciences, Washington, D.C., 1970.

24. Cargill, Inc., "De-icing Salt Saves Lives," American City, Sept., 1968.

25. Clary, Adrian G., "A Public Works Director's Dilemma," Street Salting Urban Water Quality Workshop, SUNY Water Resources Center, Syracuse University, Syracuse, N.Y., May 6, 1971.

26. DeLaVergne, Patricia, "Salt at Its Source: Livingston and Wyoming Counties, New York," Street Salting Urban Water Quality Workshop, SUNY Water Resources Center, Syracuse University, Syracuse, N.Y., May 6, 1971.

27. Environmental Protection Agency: "Environmental Impact of Highway De-icing," June, 1971.

28. Fitzpatrick, J.R., "Tungsten Carbide for Snowplow Blades," Highway Research Record, No. 173, Highway Research Board, National Research Council, Washington, D.C., 1967.

29. Fleming, Rodney R., "Getting Ready for the Storm," American City, August, 1966.

30. Fleming, Rodney R., "How to Prevent Scaling," American City, Dec., 1966.

31. Fleming, Rodney R., "More Plows and Better Plans," American City, Nov., 1968.

32. Fleming, R., "Plows and Plans for Successful Snow-fighting," American City, August, 1964.

33. The Freeman, "The Most Ignored Pollutant," March 1, 1971.

34. Fromm, H.J., "Corrosion of Auto-Body Steel and the Effects of Inhibited De-Icing Salts," Highway Research Record, No. 227, "Snow and Ice Control," Highway Research Board, National Research Council, National Academy of Sciences, Washington, D.C., 1968.

35. Godsoe, William D., "Do Road Salts Poison Water Supplies?" Boston Globe, Feb. 1, 1965.

36. Hanes, R.E., et al., "Effects of De-icing Salts on Water Quality and Biota," National Cooperative Highway Research Program Report 91, Highway Research Board, National Research Council, National Academy of Sciences, 1970.

37. Hawkins, Richard H., "Street Salting and Water Quality in Meadowbrook, Syracuse, N.Y., "Street Salting Urban Water Quality Workshop, SUNY Water Resources Center, Syracuse University, Syracuse, N.Y., May 6, 1971.

38. Hayward, H.E. and Bernstein, L., "Plant-Growth Relationships on Salt-Affected Soils," Botanical Review.

39. Highway Research Board, "Highway Research Record Report No. 193 on Environmental Considerations in the Use of De-Icing Chemicals," Washington, D.C., 1967.

40. Highway Research Board, "Snow Removal and Ice Control Research," Special Report No. 115, 1970.

41. Hofstra, G. et al., "Injury on Roadside Trees: Leaf Injury on Pine and White Cedar in Relation to Foliar Levels of Sodium and Chloride," Canadian Journal of Botany 49: 613, 1931.

42. Holmes, Francis W., "Effects of De-Icing Salt on Roadside Trees," Shade Tree Laboratories, University of Massachusetts, 1966.

43. Holmes, Francis W., "Effects of Use of Snow Control Chemicals on Street Trees," presented at the 39th Annual Meeting of New Jersey Federation of Shade Tree Commission, Nov. 16, 1964.

44. Holmes, F.W., "Salt Injury to Trees", Phytopathology, 51:10, October, 1961.

45. Holmes, F.W. and Baker, J.H., "Salt Injury to Trees, II. Sodium and Chloride in Roadside Sugar Maples in Massachusetts," Phytopathology 56: 6, June, 1966.

46. Hopt, Roger L., "Complete Salting - Sanding Economic Study," Idaho Dept. of Highways, Maintenance Division, Boise, Idaho April, 1971.

47. Hutchinson, F.E., "The Effects of Highway Salt on Water Quality in Selected Maine Rivers," Street Salting Urban Water Quality Workshop, SUNY Water Resources Center, Syracuse University, Syracuse, N.Y., May 6, 1971.

48. International Shade Tree Conference, Inc., Shade Tree Evaluation, ed. Prof. Clarence E. Lewis, 1970.

49. Judd, John H., "Lake Stratification Caused by Runoff from Street De-icing," Street Salting Urban Water Quality Workshop, SUNY Water Resources Center, Syracuse University, Syracuse, N.Y., May 6, 1971.

50. Kothiemer, John, et al., Salt Injury to Roadside Trees: II - A Progress Report," Forest Notes, Spring, 1965.

51. Kunkle, S.H., "Effects of Road Salt on a Vermont Stream," Street Salting Urban Water Quality Workshop, SUNY Water Resources Center, Syracuse University, Syracuse, N.Y. May 6, 1971.

52. Lacasse, Norman L., et al., "Maple Decline in New Hampshire," Phytopathology, 34:9, Sept. 1964.

53. Lucier, T.E., "High-Speed Snow Removal," American City, Sept., 1968.

54. Massachusetts Legislature, "Legislative Research Council Report Relative to the Use and Effect of Highway De-Icing Salts," Jan., 1965.

55. Meyer, Catherine, "Substitutes for Salt," Boston Globe, Jan. 18, 1971.

56. Monk, Ralph W., et al., "Salt Tolerance and Protoplasmic Salt Hardiness of Various Woody and Herbaceous, Ornamental Plants," Plant Physiology, p. 438, April, 1961.

57. National Geographic, "Snow Removal Danger Cited to Urban Trees and Grass," News Bulletin, National Geographic Society, February 25, 1970.

58. Nelson, John W., "Stop Plowing--Start Squeegeeing," American City, Sept., 1968.

59. Prior, G.A., "A Study of Salt Pollution of Soil by Highway Salting," from "Highway Research Record Report No. 193 on Environmental Considerations in Use of De-icing Chemicals," pp. 8-21, Highway Research Board, National Research Council, National Academy of Sciences, Washington, D.C., 1967.

60. Providence Journal, "School Board Weighs Salt Pollution Problem," July 22, 1970.

61. Rutland Herald, "Road, Environment Officials to Discuss Salt-Ban Demand," Dec. 11, 1970.

62. Salt Institute, "Survey of Salt, Calcium Chloride and Abrasive Use for Street and Highway De-Icing in the United States and in Canada for 1966-1967."

63. Salt Institute, "The Case for Road Salt," Winter, 1971-72.

64. Salt Institute, "The Snowfighter's Handbook," 1967.

65. Salt Institute, "The Snowfighter's Salt Storage Handbook," 1968.

66. Schraufnagel, F.M., "Pollution Aspects Associated with Chemical De-Icing," from "Highway Research Record Report No. 193 on Environmental Considerations in the Use of De-Icing Chemicals," Highway Research Board, Washington, D.C., 1967.

67. Schwartz, Francis X., "Make Pavements Skid Resistant," American City, May, 1970.

68. Sharp, Robert W., "Road Salt as a Polluting Element," Street Salting Urban Water Quality Workshop, SUNY Water Resources Center, Syracuse University, Syracuse, N.Y., May 6, 1971.

69. Shortle, W.C., et al., "Relative Sodium Chloride Tolerance of Common Roadside Trees in Southeastern New Hampshire," Plant Disease Reporter, 54:5, May, 1970.

70. Sloane, Edgar, "Melting Snow on a Mountain Pass Highway By Using Coal Dust," Highway Research News No. 29, Highway Research Board, Autumn, 1967.

71. Snyder, M. Jack, "Protective Coatings to Prevent Deterioration of Concrete by De-Icing Chemicals," National Cooperative Highway Research Program Report 16, Highway Research Board, National Research Council, National Academy of Sciences, 1965.

72. Spraker, Leslie, "Fight Salt Damage," Boston Globe, July 4, 1971.

73. Southworth, Anne, et al., Winchester Citizens' Report on De-icing Salts, March 6, 1971.

74. Stark, Linda, "Towns Fear Road Salt Pollutes Water Supply," Boston Globe, January 31, 1971.

75. Steel, "Detroit Faces New Battle Against Rust," March 2, 1964.

76. Struzeski, Edmund J., "Environmental Impact of Highway De-Icing," Street Salting Urban Water Quality Workshop, SUNY Water Resources Center, Syracuse University, Syracuse, New York, May 6, 1971.

77. Thomas, Lindsey Kay, "Road Salt (Sodium Chloride) Injury to Kentucky Bluegrass," Highway Research Record No. 161, "Roadside Development," Highway Research Board, National Research Council, National Academy of Sciences, Washington, D.C., 1967.

78. Walton, G.S., "Phytotoxicity of NaCl and $CaCl_2$ to Norway Maples," Phytopathology 59:1412, October, 1969.

79. Wester, H.V. and Cohen, E.E., "Salt Damage to Vegetation in the Washington, D.C. Area During the 1966-1967 Winter," Reprint from Plant Disease Reporter, 52:5, May, 1968.

80. Westing, A.H., "Plants and Salt in the Roadside Environment," Phytopathology 59: 1174-81, September, 1969.

81. Whitman and Howard, Inc., "Report Relative to Salt Contamination of Existing Well Supplies - Town of Burlington, Mass.," October, 1971.

82. Whitney, Craig R., "Anti-Snow Salt Extracts Price: Corrosion," New York Times, Jan. 2, 1970.

83. Whittle, Carolyn L., "The Case Against the Use of Highway Deicing Salts for Snow & Ice Control in Newton." October 1, 1971.

84. Waller, Julian A., M.D., "Road Salting and Highway Safety," undated paper.

85. American City, "Snow Melting for 64 cents per Ton," November, 1966.

86. Woodcock, A.H. 1957. Salt and Rain. Scientific American, October, 1957: 42-47.

87. Loucks, R.H. and J.W. Winchester. 1970. Pollution contributions to the atmospheric inventory of chlorine and bromine in aerosols over continental U.S.A. pp. 233-250 in Trace Substances in Environmental Health (ed. D.D. Hemphill), Vol. III University of Missouri.

88. Eriksson, E. 1959. The yearly circulation of chloride and sulphur in nature: meteorological, geochemical and pedological implications. Tellus, 11: 375-403; 12:63-109

APPENDIX A

SALT-RELATED DAMAGE TO CONCRETE

Mechanisms of Concrete Deterioration

Research indicates that there are basically two mechanisms by which concrete bridge decks can deteriorate: scaling, in which salt plays a non-chemical role, and spalling, in which salt's participation is chemical. Scaling represents a fairly shallow peeling or chipping from the surface of the bridge deck, while spalling appears as deeper, more pronounced chipping.

Originally scaling was thought to be related to chemical action or crystal growth of salt (23), but now is believed to be the result of hydraulic pressures and the differential expansion and contraction of freezing brine in the concrete. Scaling occurs when salt, in solution with melted snow and ice, penetrates the concrete through surface pores and capillaries. As more salt penetrates the concrete, a depth-wise gradient of salt concentration (and, therefore, of the freezing points) occurs. The higher concentration of brine toward the surface will freeze at a lower temperature than the lower concentration of brine toward the interior. Thus, during a period of falling temperatures, when the surface brine reaches a low enough temperature to begin to freeze, and therefore to expand, the expansion pressure from the surface is blocked by the interior brine, which has already frozen and expanded at a higher temperature earlier in the period. The resulting interior pressure can result in destructive scaling unless certain precautions, notably adequate air-entrainment (adding minute air bubbles into the concrete mix) and proper finishing, are taken during construction of the bridge deck. In general, scaling damage appears to be the cumulative result of a number of freeze-thaw cycles, with the better designed and constructed bridge decks able to resist a higher number of freeze-thaw cycles in the presence of de-icing salts. Salts, in turn, tend to increase the number of freeze-thaw cycles, and therefore, accelerate the deterioration process (23, 27, 54, 71).

Concrete spalling, a more serious chipping of the bridge deck surface, is the result of a mechanism which can occur without de-icing salts, but which is significantly accelerated by the presence of salts. Spalling is the product of the corrosion of steel reinforcing bars, which are laid to form several mats in a bridge deck and covered by a certain thickness of concrete. Water or brine penetrates to the reinforcing bars through hairline cracks

in the concrete overlay, creating an environment for the corrosion process (oxidation of iron in the presence of water). When steel corrodes, it expands, and this creates internal pressure within the bridge deck which can result in deterioration of the concrete in the form of chipping or spalling. The actual corrosion of iron is directly related to an electrolytic reaction, and the presence of salt in the water greatly heightens the conductivity of water. The rate of corrosion, therefore, depends on the amount of salt present in solution as well as the availability of oxygen for combination. Thus salt contributes directly to steel corrosion, which in turn causes concrete spalling (13, 40, 23, 27).

Other Factors Contributing to Deterioration

While salt can be seen to participate quite directly in the scaling and spalling processes, empirical evidence indicates that the conditions necessary for these processes to occur are created by other, related factors. The absence of these factors can either prevent altogether or greatly inhibit the progress of deterioration in bridge decks. Studies of the problem frequently mention the need for adequate curing of concrete made with Portland cement (from 6 to 12 months) before exposure to de-icing salts, to which it is most vulnerable when improperly cured (27, 54). Insufficient air-entrainment (less than 6%) is seen to lead to scaling due to inadequate compressive strength (27, 54, 71), while the thickness of concrete cover over reinforcing steel can fall below specifications (sometimes to as low as ½") if the bars are improperly placed, leading to rapid brine intrusion and consequent spalling. The thickness of concrete cover relates directly to chloride content at the level of reinforcement, which is approximately halved for each additional inch of cover. A minimum of 2", with a preferred 3" cover has been recommended (40). Also, the ratio of water to cement in the concrete mix has been shown to have a pronounced effect on the porosity of cement paste, and therfore, on the permeability of the finished deck. A water to cement ratio of 5-5-½ gallons per sack of cement has been recommended (40).

Preventative Methods

Many of the factors associated with bridge deck deterioration can be controlled through proper design specifications through proper mixing, transporting, laying and curing of concrete, and by adequate field inspection, the lack of any one of which may contribute to eventual damage by scaling and spalling (27, 54). Also, the Highway Research Board has conducted extensive testing of protective coatings to prevent damage by de-icing salts, with the best results on the basis of protection and economy obtained

with a solution of linseed oil (71). Another substance, a chlorinated rubber curing compound available commercially is reported (30) to reduce scaling damage, although no results from controlled tests have been found to date.

APPENDIX B

Salt Contamination of Well Water Supply, Burlington, Mass.

The first town in the Boston Metropolitan area to ban the use of de-icing salts was Burlington, an industrialized suburb located along Boston's main circumferential highway, Route 128. Burlington's ban was promoted by the steady increase in the chloride concentration in its well water supply, which in 1971 reached 110 ppm for all wells, and as high as 198 ppm in its Great Meadow Well Field. The U.S. Public Health Service has set as the upper limit for chloride contamination 250 ppm, at which level Burlington's contaminated wells would have to have been removed as a source of public water.

Following the institution of the ban on de-icing salts by a vote of the Town Meeting (which in fact affected only Town-maintained roads, and not the State-maintained Routes 128, 3 and 3A), there ensued considerable controversy as to the source of the chlorides. The Salt Institute, a public relations organization promoting the use of de-icing salts, contended that a poorly protected salt pile belonging to the Burlington Department of Public Works was the chief source, while others cited road run-off from both State and Town roads as the primary source.

To determine the source of contamination, Burlington commissioned an engineering firm, Whitman & Howard, Inc. of Boston, to investigate probable sources and explore possible methods of controlling further contamination. The report (ref. 81) completed in October, 1971, determined that, according to computations based on test borings performed by the U.S. Geological Survey at the site of the salt storage pile (which had actually been removed in 1966), only 12% of the well contamination attributed to de-icing was coming from the salt storage site, with the rest coming from runoff. De-icing salts from both sources were seen to comprise approximately 85% of the chloride contamination. According to the report, "It can be concluded that the use of salt for highway de-icing, in conformance with the so-called 'bare pavement' policy, constitutes the primary source of salt pollution. Salt used for the de-icing of parking lots also makes a definite contribution to this contamination. It is our opinion that 'highway de-icing chemicals contribute about 85% of the chloride contamination in the Vine Brook basin and domestic and industrial sources contribute 15%,' as stated in the report, 'Salt contamination of the Town of Burlington Wells in the Vine Brook Basin' is fairly accurate."

APPENDIX C.

NATURAL INPUTS OF SALT INTO THE CONTINENTAL U.S.A.

(Contributed by I. C. T. Nisbet)

The main natural source of salt into terrestrial North America is from the ocean. When ocean waves break, droplets of salt spray are thrown into the air: these evaporate to form minute particles of salt which may be carried over land by the wind. Some of these particles fall out directly on land; others act as nuclei for raindrops and are carried down in the rain. Indeed, salt particles appear to play an important role in the formation of raindrops and thus help to determine rainfall patterns (86). Under natural conditions, the input of salt in the rain, together with a contribution from leaching of mineral salt deposits, was more or less balanced by the outflow in rivers. The salinity of rivers was higher than that of rainwater, primarily because much water which falls in rain evaporates before it reaches the rivers, leaving the salt behind.

The annual natural input of chlorides from the ocean to the continental United States has been estimated by Loucks and Winchester (87) to be of the order of 4 million tons per year, with possible extremes of 1 and 7 million tons. Thus road salting, which already contributes 5-6 million tons of chlorides per year, has probably more than doubled the chloride input to the entire continental United States. (Other artificial inputs, such as industrial use of salt and release of brines in conjunction with oil drilling, are additional.)

Natural input of salt to the "snow belt" is of course only a proportion of that into the continent. According to figures for rain-out computed by Loucks and Winchester (87), the snow belt can be divided into two parts. In the Appalachian and coastal states from Maine to Virginia, an area of roughly 600,000 km^2, the average rate of precipitation of chlorides in rain and snow is about 4kg/(hectare-year), corresponding to an input of chlorides of about a quarter of a million tons. Dry precipitation is estimated to be about twice as much as wet precipitation (88), so that the total natural input of chlorides to this area would be about three-quarters of a million tons. In the other northern states between the Appalachians and the Rockies, an area of about 2 million km^2, the average rate of precipitation of chlorides in rain and snow is slightly less than 1 kg/hectare-year) (87), so that the total input of chlorides is about half a million tons. The inputs of chlorides to these areas in road salt were 1.2 and 1.4 million tons respectively as long ago as 1966-67 (27) and have probably doubled since then.

In coastal cities, a substantial fraction of the salt used on roads probably runs off into sewers and more or less directly into the ocean. Inland, the fate of the salt is not well known. Figures quoted in the text suggest that a quarter to a half enters the soil, the rest going into rivers and lakes. Measurements of the chloride load of six major rivers, summarized in ref. 36, indicate substantial peaks between January and April. However, only in the Ohio and Mississippi Rivers, in each of which the winter peak accounted for about a million tons each year, were the chloride loads significant. Much of this winter peak would be of natural origin (snowfall and mineral leaching) and there was no significant increase in these two major rivers between 1959 and 1963 despite rapidly increasing use of salt on roads. Although it is not yet possible to calculate an exact salt budget for the snow belt, I conclude that only part of the input of road salt can be accounted for as excess outflow in rivers, and that at least half must enter ground water and lakes. Hence the rate of natural input of salt to ground water and lakes in the snow belt must have been at least doubled, probably quadrupled, by road salting (without considering industrial inputs).

The situation is of especial concern in the Great Lakes. The natural input of chlorides to the area drained by the four lower lakes (Michigan, Huron, Erie and Ontario) is only about 200,000 tons per year (87). Yet as long ago as 1960, chlorides from road salts contributed a further 1,100,000 tons per year, and there were substantial further inputs from industrial sources (27). The volume of water in Lakes Erie and Ontario is only about 4,000 km^3, so even if chloride inputs were to level off at one million tons per year, road salting alone would increase the mean chloride levels by 25 mg/l, assuming a turnover time of roughly 100 years. The average chloride level in Lake Erie has already increased from 7 mg/l in 1910 to 23 mg/l in 1964 (27).

A final question arises from the observation that substantial quantities of road salt are thrown into the air by vehicles (see text). The size distribution of the resulting salt particles does not appear to be known, but if they are comparable in size to natural salt particles they could remain in the air for long periods and increase significantly the atmospheric salt load in the areas concerned. In this way road salting could affect patterns of winter rainfall and snowfall -- a possibility that should be investigated.